DIVISION S-7—FOREST AND RANGE SOILS

Readily Oxidizable Carbon: An Index of Decomposition and Humification of Forest Litter[1]

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ABSTRACT

The forest floor is an important component of the forest ecosystem. The reactions taking place at this interface between the organic horizons and the mineral soil are strategic. The rate of CO_2 evolution from the forest floor is indicative of the biological activity occurring in the organic horizons and is also indicative of the readily available energy material present. The amount of CO_2 evolved over a 28-day period was determined for the F-layers (decomposing material) and H-layers (humified material) from hardwood, conifer, and mixed hardwood conifer forests in the northeastern United States. Total CO_2 evolved appeared to be indicative of the level of readily oxidizable carbon in the material and its state of decomposition and humification. A more rapid method of evaluating decomposition and humification appeared desirable. Water soluble carbon was determined on the same materials used for the CO_2 evolution study plus fresh litter from some of the same stands. The values for soluble carbon compared very favorably with those from CO_2 evolution determinations. It was thus concluded that the more rapid soluble carbon determination is a useful index of state of decomposition and humification.

Additional Index Words: soluble carbon, CO_2 evolution, forest floor, decomposition.

ACCUMULATION of fresh litter on the forest floor stimulates marked increases in microbial populations and respiratory activities. Then as decomposition proceeds, microbial populations and respiratory activities gradually decrease to relatively low levels as "stable" humus is formed. This sequence reflects an initial high level and then a gradual decrease in readily available carbon as microbial energy source material. We postulated (i) that CO_2 evolution from aerobic incubation should be a good index of stage of decomposition and humification of forest floor materials and (ii) that water soluble carbon as a dominant energy source for microbial respiration should also be a good index of decomposition and humification. The objective of this study was to test these relationships in the hope that the easier, much more rapid soluble carbon assay would suffice in place of tedious incubation procedures.

The importance of the forest floor has been well recognized for many years. Many of the early studies on the forest floor were largely descriptive, the emphasis being on chemical composition, morphology, and classification (1, 3, 13, 15). Only a few of these early studies considered the decomposition processes (5, 11). Although some recent studies are still descriptive (7, 17), much of the current work is concerned with the nature of decomposition, i.e., biochemical processes and mineralization of plant nutrients, particularly nitrogen (2, 9, 10, 12, 14, 16).

METHODS AND MATERIALS

Materials known to be different with respect to state of decomposition and humification were collected from northeastern United States forests having distinct L, F, and H layers. F1 and F2 layers were recognizable in some instances. Samples were collected in the fall. Stands sampled included conifer, hardwood, and mixed conifer and hardwood types. Six 0.09-m^2 samples were taken in each stand. The L, F (or F1 and F2), and H layers were separated and sampled individually. Samples were air dried and ground to pass a 20-mesh sieve.

Prior to CO_2 evolution and water soluble carbon determinations, moisture content and saturation capacity were determined for each sample. Sample weights for all determinations were on an oven dry basis.

CO_2 Evolution—Duplicate 15-g samples adjusted to 50% of saturation capacity were incubated in 250-ml Erlenmeyer flasks under continuous aeration (4). Air passed through the incubation flasks was first scrubbed through a series of alkaline and acid solutions (10% NaOH, 10% H_2SO_4, 10% $Ba(OH)_2$ and distilled water) to remove CO_2 and prevent sample drying. The evolved CO_2 was absorbed in 8 ml of 1*N* NaOH in 1.8- by 15.2-cm collection tubes. The tubes were changed every 3 days

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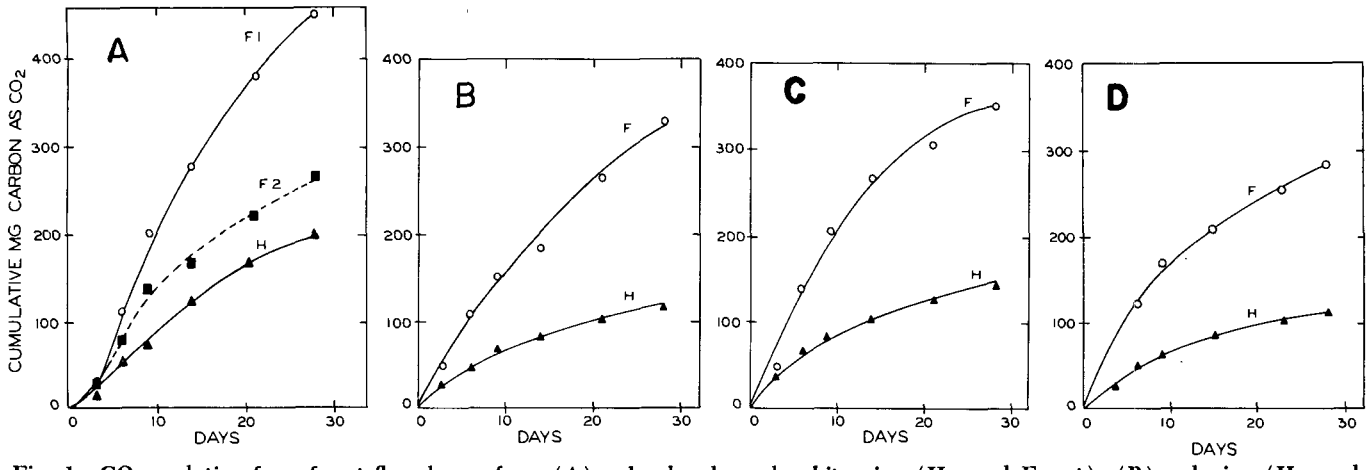

Fig. 1—CO_2 evolution from forest floor layers from (A) red oak-red maple-white pine (Harvard Forest); (B) red pine (Harvard Forest); (C) Norway spruce (Harvard Forest), and (D) hemlock-yellow birch (Adirondack Mountains) stands.

Table 1—Soluble C, CO_2 evolution, and respiratory C/soluble C ratios for forest floor materials from eastern United States forests

Forest type§	Layer	Mg soluble C per g material	Mg C as CO_2 evolved per g material	Respiratory C/soluble C ratio
Red oak-red maple white pine*	L	56.4	--	--
	F1	16.1	30.2	1.9
	F2	14.8	17.7	1.2
	H	7.6	8.5	1.1
Red oak-red maple*	L	60.6	--	--
	F1	13.1	19.1	1.5
	F2	14.6	12.7	0.9
	H	10.7	11.6	1.1
Hemlock-red-oak-yellow birch*	L	56.8	--	--
	F1	23.4	--	--
	F2	14.8	12.5	0.8
	H	7.8	9.4	1.2
White pine-red oak red maple-hemlock*	L	36.5	--	--
	F	14.5	22.3	1.5
	H	8.1	8.5	1.0
White pine*	L	45.8	--	--
	F	15.0	22.0	1.5
Norway spruce*	L	35.9	--	--
	F	17.8	23.6	1.3
	H	7.4	9.3	1.3
Red pine*	L	33.5	--	--
	F	15.1	22.0	1.5
	H	7.5	7.4	1.0
Red spruce-yellow birch†	F	12.9	17.8	1.4
	H	7.0	11.1	1.6
Hard maple-basswood†	F	16.1	27.2	1.7
Hard maple-beech†	F	16.7	25.1	1.5
Hemlock-yellow birch†	F	14.7	19.1	1.3
	H	6.1	7.1	1.2
Red oak-hard maple white ash-yellow poplar‡	F	16.6	23.3	1.4
Red oak-hard maple‡	F	17.1	20.5	1.2

* Harvard Forest, Petersham, Massachusetts.
† Adirondack Mountains, New York.
‡ Black Rock Forest, Cornwall, New York.
§ Red oak (Quercus rubra L.); red maple (Acer rubrum L.); white pine (Pinus strobus L.); hemlock [Tsuga (Endl.) Carr]; yellow birch (Betula alleghaniensis Britton); Norway spruce (Picea excelsa L.); red pine (Pinus resinosa Ait.); red spruce (Picea rubens Sarg.); basswood (Tilia L.); beech (Fagus L.); white ash (Fraxinus americana L.); and yellow poplar (Liriodendron tulipifera L.).

through 9 days, then at 14, 21, and 28 days. Determination of absorbed CO_2 was made by titration using a Beckman model K automatic titrimeter. Results are expressed either as cumulative mg carbon evolved as CO_2 over the 28-day period or as total mg carbon evolved as CO_2 per gram of forest floor material for the total 28-day period.

Water Soluble Carbon—A method developed by Gilmour et al. (8) was used for soluble carbon analyses. Duplicate 10-g samples were placed in 250-ml Erlenmeyer flasks and an excess of 100 ml of distilled water over saturation capacity was added for extraction of soluble carbon. The samples were shaken on a reciprocating shaker for 12 hours at room temperature. Samples were filtered through a Büchner funnel.

A wet presulfate oxidation technique was used for combustion. Duplicate aliquots of each sample extract were pipetted into a 50-ml Erlenmeyer flask fitted with a center well to hold a CO_2 absorption vial. Volume was adjusted to approximately 10 ml with distilled water and 0.3 ml of 5*N* H_2SO_4 was added. After swirling the flask gently, 1 ml of 4% $AgNO_3$ was added to precipitate free chlorides and act as a catalyst for the oxidation process. Approximately 1.5 to 2 mg of potassium persulfate were than added. About 2 ml of 5*N* NaOH were added to the center vial. The flask was capped with a serum cap and evacuated using a 20-gauge hypodermic needle. The flask was then placed in an oven at 70 to 75C for 2 hours. After cooling, the center vial was removed and the contents washed into a 50-ml Erlenmeyer flask. Absorbed CO_2 was determined by titration using the Beckman autotitrimeter. Results are expressed in milligrams soluble carbon per gram of forest floor material.

RESULTS AND DISCUSSION

CO_2 Evolution—Data for CO_2 evolution for selected samples are presented graphically in Fig. 1. These data show that the CO_2 evolution rates are greater for the less humified F1 layers than for the more humified F2 and H layers. A rapid initial respiration rate for the less humified material was apparent and though gradually diminishing, persisted over the 30-day incubation period. As expected these materials had a larger readily-available energy source than the more humified materials. For the first 2 days, the rate of CO_2 evolution for the less humified materials in some samples was about the same as or only slightly greater than that for the more humified materials. However, after 2 days, the rate for the less humified materials increased rapidly (Fig. 1*A*). This apparently represents a build up of microorganisms in response to the larger source of readily available carbon in the less humified materials than in the more humified materials. The CO_2 evolution data presented in Table 1 consistently indicate higher levels of CO_2 evolution in less humified layers. These can be ranked as follows: F1 > F2 > H and F > H. From these data, it can be concluded that CO_2 evolution values can be used as a measure of stage of decomposition and humification. This relationship holds for both hardwood (Fig. 1*A* and Table 1) and conifer (Fig. 1*B*, 1*C*, and Table 1) stands.

Soluble Carbon—Since CO_2 evolution by incubation takes so long, a method giving equivalent information more quickly is highly desirable. The analysis for water soluble

carbon appears suitable. Comparative values for soluble carbon and CO_2 evolution are given in Table 1 for selected samples from eastern United States forest types. The levels of soluble carbon were consistently higher in the less decomposed materials and decreased with increased decomposition and humification. The variance between values for soluble carbon and CO_2 evolution was least for the more decomposed and humified layers. The relationship between CO_2 evolution and soluble carbon, may be expressed as $Y = 0.13 + 1.2996\ X$ ($r = 0.78$).

Comparison of data for CO_2 evolution and levels of soluble carbon from the same organic layers showed that aerobic incubation of materials high in soluble carbon resulted in high rates of CO_2 evolution. Conversely, incubation of forest floor material having low levels of soluble carbon yielded low rates of CO_2 evolution. The relationship was consistent enough to warrant use of soluble carbon as an index to respiratory activity or extent of decomposition and humification. Data for 23 additional sample areas in the eastern United States together with that in Table 1 showed that levels of soluble carbon less than 12 mg/g of material were indicative of well decomposed and humified forest floor (H-layer) material; 12–20 mg/g of material were indicative of moderately decomposed and humified layers (F-layer); and more than 20 mg/g of material were indicative of relatively undecomposed layers (L-layer) (Lily Jho-Yuan Hu. 1969. Soluble carbon and respiration of forest humus. M.S. thesis. Oregon State University).

Since only 2 days are required for soluble carbon analysis as compared to 28 days for CO_2 evaluation incubations, the soluble carbon determinations are preferred.

LITERATURE CITED

1. Alway, F. J., J. Kittredge, Jr., and W. J. Methley. 1933. Composition of the forest floor layers under different forest types on the same soil type. Soil Sci. 36:387–398.
2. Birch, H. F. 1959. Further observations of humus decomposition and nitrification. Plant Soil XI:262–286.
3. Bodman, G. B., and J. Kittredge, Jr. 1938. Description of forest floors from several important forest types of the Sierra Nevada Basalt Plateau and Coast Ranges in Northern California. Soil Sci. Soc. Amer. Proc. 2:509–521.
4. Bollen, W. B. 1941. Soil respiration studies on the decomposition of native organic matter. Iowa State College. J. Sci. 15:353–374.
5. Broadfoot, W. M., and W. H. Pierre. 1939. Relation of rate of decomposition of tree leaves to their acid-base balance and other chemical properties. Soil Sci. 48:329–348.
6. Draper, N. R., and H. Smith. 1967. Applied regression analysis. John Wiley, New York. 407 p.
7. Gessel, S. P., and A. N. Balci. 1965. Amount and composition of forest floors under Washington coniferous forests. p. 11–23. *In* C. T. Youngberg (ed.) Forest-soil relationships in North America. Oregon State University Press.
8. Gilmour, C. M., F. Merryfield, F. Burgess, L. Punkerson, and K. Carswell. 1961. Persulfate oxidizable carbon and BOD as a measure of organic pollution in water. p. 143–149. *In* Proc. 15th Purdue Industrial Waste Conf., Lafayette, Ind. Purdue Univ.
9. Handley, W. R. C. 1961. Further evidence for the importance of residual leaf protein complexes in litter decomposition and supply of nitrogen for plant growth. Plant Soil XV:37–73.
10. Ivarson, K. C., and F. J. Snowden. 1959. Decomposition of forest litter: I. Production of ammonia and nitrate nitrogen, changes in microbial population, and rate of decomposition. Plant Soil XI:237–248.
11. Melin, E. 1930. Biological decomposition of some types of litter from North American Forests. Ecology 11:72–101.
12. Mikola, P. 1958. Liberation of nitrogen from alder leaf litter. Acta Forest. Fenn. 67:1–10.
13. Rommell, L. G., and S. O. Heiberg. 1931. Types of humus layer in the forests of northeastern United States. Ecology 12:567–608.
14. Voigt, G. K. 1965. Nitrogen recovery from decomposing tree leaf tissue and humus. Soil Sci. Soc. Amer. Proc. 29: 756–759.
15. Wilde, S. A., S. F. Buran, and H. M. Galloway. 1937. Nutrient content and base exchange properties of organic layers of forest soils in the Lake Slater region. Soil Sci. 44:231–239.
16. Witkamp, M. 1963. Microbial populations of leaf litter in relation to environmental conditions and decomposition. Ecology 44:370–377.
17. Youngberg, C. T. 1966. Forest floors in Douglas-fir forests: I. Dry weight and chemical composition. Soil Sci. Soc. Amer. Proc. 30:406–409.